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NOTES ON EARLY PRACTICE IN BRIDGE BUILDING.

By GEORGE E. GRAY, Hon. M. Am. Soc. C. E.

PRESENTED NOVEMBER 18TH, 1896.

WITH DISCUSSION.

In reviewing the paper entitled "What Is the Life of an Iron Railroad Bridge?"* by J. E. Greiner, M. Am. Soc. C. E., and the discussion on it, the author was particularly interested in the remarks of T. C. Clarke, M. Am. Soc. C. E., and Walter Katté, M. Am. Soc. C. E., referring to certain bridges on the New York Central and Hudson River Railroad. The conclusions arrived at by these members on this question are, in the author's opinion, generally correct. These conclusions are that the practice of placing the diagonals closer than is now customary led to diffusing the strains over a large number of points rather than concentrating them on a few, which is one of the reasons the bridges stood so well. Mr. Katté was of the opinion that solidly riveted lattice girders, up to spans not exceeding 200 ft., give unquestionably the best service for such constant and heavy traffic as that on the New York Central system.

* See Transactions, Vol. xxxiv, p. 294.

It was contemplated in the original design for the bridges referred to, to connect all of the parts by riveting, thus diffusing the strains throughout the whole structure. The advantage of this system was soon clearly illustrated at a bridge of this type just erected over the Erie Canal near Newark, N. Y. A fast express passenger train was bound westward, and as it approached within a few feet of this bridge the axle of the forward driving wheels, outside connections, broke off close to the right-hand wheel. This left the wheel free, and, being propelled with great velocity forward, it left the rail, striking in its course the second outside right-hand post, from the easterly end of the bridge, cutting the post off entirely, together with several tension bars. In addition, the third and fourth posts were nearly severed and several tension bars more or less cut away, but the rigid connections of the structure carried the train over safely, and, in fact, there was no delay in passing all other trains while repairing the damage. It is gratifying to the author to hear, after so many years, such testimony in recognition of the labor and efforts of himself and his able assistant, the late Col. Howard Carroll.

The bridges referred to were designed and constructed before 1864 and 1865. It may be of some interest, historically, to engineers and others to know, what the author believes to be true, that the New York Central Railroad Company was the first to build an all wrought-iron bridge of any considerable span for railroad use in the United States. Several bridges, cast and wrought iron combined, had been constructed on the Whipple and other designs, but the failure of one of them on the New York and Erie Railroad, through the ignorance of track men, caused railroad officials to look with distrust on any iron bridge.

The process that led up to the adoption of iron for bridges in the United States was slow. The author, as chief engineer of the New York Central Railroad Company, was directed to examine carefully into the subject of iron bridges and report to its Board of Directors. The high price of iron and the general lack of knowledge of its use for such purposes in the United States made it difficult to get a reasonable consideration of the subject by those high in authority. In working out the plans and strain sheets a serious question arose as to how much a given section would bear under compression without bending. Upon this question the highest authority then accessible

was silent, and the author had to work it out by erecting the proper testing machinery for that purpose at the New York Central shops at Albany, N. Y. Finally, when authority was obtained and plans and estimates prepared, the directors and officials were skeptical. To convince the skeptics, a single-track bridge of 30-ft. span, proportioned to 1 ton per lineal foot, was built at Schenectady, solely for tests, and to be so used until broken.

A 28 to 30-ton locomotive, the heaviest then on the road, was run over this bridge at high speed without any defects appearing. Thereafter the bridge was loaded by dead weight, evenly distributed, to over 4 tons per lineal foot, when the bridge failed from a defective tension bar. Up to this period the rule had been to proportion all bridges to a load of 1 ton per lineal foot. Soon after the rule was changed to a proportion of 2 tons per lineal foot, this being in view of the demands of increasing traffic and the constant tendency to enlarge the capacity of locomotives and rolling stock generally.

The question of corrosion entered seriously into the author's calculations originally. Skeptics made telling arguments as to the unreliability of iron on that account, therefore extra precautions were taken to protect each part of the iron promptly on delivery. Long after, so anxious had the author become on this subject, and fearing neglect to keep the bridges well protected from so insidious an enemy, he wrote from California to his direct successor, Mr. Charles Hilton, and again to Mr. Charles H. Fisher, his successor, both among his former assistants on that road, calling their attention to this subject and urging watchfulness and care. Mr. Fisher replied, that, mindful of the danger, he had called the attention of his superiors to this subject; that they had expressed no concern, were apparently indifferent, and, furthermore, said that the danger, if any, was so remote there was no need of apprehension. An inspection of the bridges referred to should bear witness of any damage by corrosion after a period of 35 years or more.

Can the engineer be held responsible when his principals are so indifferent to the inroads of such an enemy as corrosion, in fact, the only enemy of any account the engineer has to fear?

The author is wedded to rigid connections and would not limit spans to 200 ft., as proposed by Mr. Katté, except on economical grounds, such as rapid erection, or the continuous running of trains

during erection. Riveted connections largely avoid vibration, the great demoralizer of all iron and steel bridges. It is his firm belief that had a bridge with pin connections been in the place of the present bridge at Newark, erected over 32 years ago, the whole train, with its precious load of passengers, would have been plunged into the Erie Canal below.

To the engineer of this date, with all the accumulated knowledge and experience of the past 35 years, with perfection of machinery and material and the developed science of bridge building, the foregoing remarks may seem not worth commenting upon; but he should feel thankful that those who preceded him had made his road easier and that he is not hampered, as they were, by lack of experience, a very meager bridge literature and prejudiced opposition.

DISCUSSION.

GEORGE H. THOMSON, M. Am. Soc. C. E.—The author's early advocacy of iron bridges for the New York Central Railroad and his persistent efforts with the railroad officials, resulting in the adoption of wrought-iron structures, are not generally recognized as they should be. As chief engineer of that line, he had for his bridge assistant Col. Howard Carroll, whose first work was the bridge over the Mohawk River at Schenectady, still in service.

Col. Carroll designed in riveted lattice. In the grouping of rivets for specific stress modern designs do not excel, and often do not equal, the nicety and precision shown in some of his early bridges. For tension, he used flats or plates only; for compression, he used angles latticed, or angles and plates. His top chords were of plates and angles, and continuous throughout the entire length; his floors were made of track stringers and floor beams (plate girders), except in double-track bridges, where the floor beams were of lattice trusses. His lateral systems were of flats. In one of his bridges still in service rivets of $\frac{3}{4}$, $\frac{7}{8}$, 1, $1\frac{1}{2}$ and $1\frac{1}{4}$ ins. diameter are found. He used panel-point plates in his truss connections. The first specification for riveted bridge work known to the speaker as made by Carroll is dated 1857; it is the prototype of current specifications for riveted work.

Mr. Charles Hilton, a pupil of Col. Carroll, took the latter's place on the New York Central and subsequently became its chief engineer. He followed Col. Carroll in design, with some modifications. In lattice bridges of the pony type, he riveted the floor beams to the verticals with rivet section in excess. In spans of 150 ft. he used the multiple system where a web tension set at 45° covers four panels of the truss as shown in Fig. 1. His top chords were like Col. Carroll's, continuous throughout the entire length; his floors were sometimes made of 9-in. I-beams, spaced 20 ins. centers, and hung from the bottom chords by tension rivets. These I-beams supported longitudinal timber stringers upon which the rails rested. His web compression members were sometimes made of rolled beams and channels.

In 1864 Mr. Hilton changed his designs. He no longer used the Pratt system, but the diagonal system. He made his subpanels about 10 ft., as shown in Fig. 2. He used stiff lateral systems everywhere. Twenty-one years ago the speaker as a draftsman drew pin-connected bridges for Mr. Hilton in which all the laterals were stiff and riveted. His tension members were of angles, or such sections as had a considerable moment of inertia, so that if any member should be called upon temporarily to do duty in compression or as a beam, it was, in a measure, available therefor.

Mr. Thomson.

Mr. Hilton's first diagonal lattice was the bridge over the Erie Canal near Canastota. The bridge is illustrated in the "Manual for Railroad Engineers," by Professor G. L. Vose, but the attachment of the floor beams to the chords was by a diaphragm distributing to both webs of chords, and not as shown in the book mentioned.

Mr. Hilton was not inclined to eccentric connections, however, and he abandoned panel-point plates after 1862. He always had in mind elastic relations, especially in truss connections, and therefore the connection of a thin angle to a thick plate is not found in his designs. Fig. 3 shows one of his diagonal-system bridges. The horizontal member $-y-$ takes both tension and compression; this member is left out in European bridges of this type. He computed trusses from engine

FIG. 1. CARROLL THROUGH LATTICE

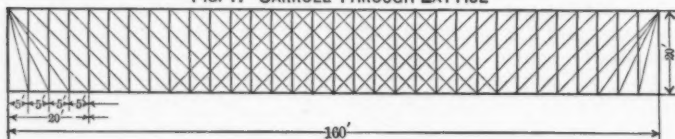


FIG. 2. HILTON THROUGH LATTICE

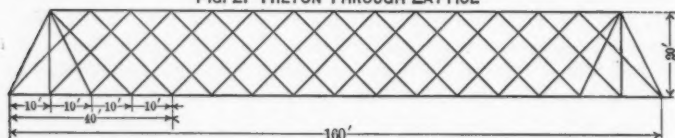
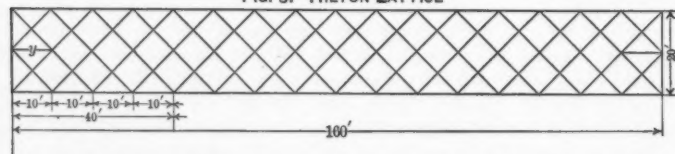


FIG. 3. HILTON LATTICE



wheels in the year 1862, and, prior to 1878, made specifications for wheel loads such as are now current.

A. S. C. Würtele, M. Am. Soc. C. E., began in 1868 to design lattice bridges following closely Mr. Hilton's practice. In 1869, S. J. Fields, M. Am. Soc. C. E., a pupil of Mr. Hilton, designed lattice bridges, following the same practice with improvements in details of chords, etc. Charles McDonald, M. Am. Soc. C. E., about 1875, also designed lattice bridges with improvements in details. In 1876, John F. Alden, M. Am. Soc. C. E., a pupil of Hilton, further improved details.

As early as 1873, the speaker talked over the matter of short versus long panels with Mr. Hilton, and in 1885 he began to use long panels,

up to 32 ft. length, in lattice bridges. After twenty years' acquaintance Mr. Thomson. with multiple systems, and consequent short panels, he is in favor of the long panels provided there is one intersection of web members, as in Fig. 4. They are cheaper, and the valid conclusions of those that favor diffusion of stress and dispersion of members hold good for them. The objection to them as regards inadequate diffusion of stress is not borne out by gauging; there is less structural motion in the long than in the short-panel lattice bridges of the same weight.

If the invasion of rivets is observed in the details of pin-connected bridges for twenty-five years past, together with continuous top chords, riveted floor beams and stringers with their rigid connections, plate girders, etc., the influence, pervasive and permanent, of Messrs. Carroll and Hilton will be detected. A modern bridge cannot be found void of the evidences of their thought and work. The ideas of engineers change. Twenty-three years ago but one shop in the

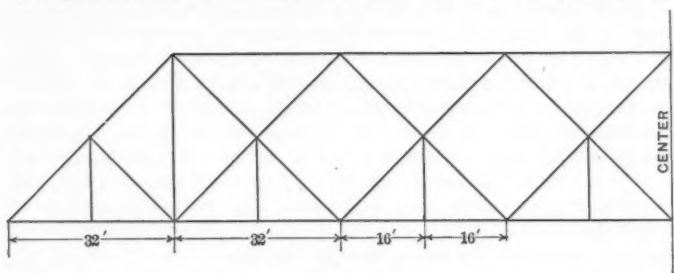


FIG. 4.

United States built lattice bridges, and ten years ago the speaker was severely criticised for advocating as economical plate girders of 100-ft. span for certain well-defined situations. Long plates are now common enough, and in his own practice he has erected about 100 spans of long plates up to 123½-ft. span since 1885.

The acceptance of rivet work has become so thoroughly established, and the principles governing the design of rivet construction as set forth and exemplified in the practice of Messrs. Carroll and Hilton are so generally followed, that the old battle of pins versus rivets seems an idle pastime. At the present date there are able engineers who do not hesitate to design an unprecedented long span suspension bridge with stiffening trusses of the lattice type, and design a drawbridge of the 1864 Hilton type.

The pin-connected bridge of modern design, barring its main connections of forged eye-bars, its non-intersection of web members, and its indirect lateral attachments, embodies the principal features of the

Mr. Thomson. lattice bridge. The future will further develop and possibly further merge the two systems.

There is much chance for advance in the design of bridges of the lattice type, but before much success can be obtained in that direction, there needs to be change in cerebration; more freedom and less "daddyism." The speaker would not undertake to define freedom, as a comprehensive consideration of all the points involved is far beyond his ability and research. However, he would attempt a definition of "daddyism," which can be considered as provisional only, as follows: "Daddyism" is that incoherent, indeterminate, indefinite and almost indescribable manifestation of consciousness as expressed through the personality, which leads the mind to assume that things as they exist, and relations between things as they obtain, are the same as one's concepts of things, and the relations between them; the result of this assumption, this mode of thinking, is error; its product is progress of the negative order, that is to say, retarded progress.

By structural motion, referred to in connection with the bridges built by Mr. Hilton, the speaker meant the motion induced in bridges by the imposition and passage of the rolling load. "Motion" *per se* cannot be defined, and a definition of structural motion would involve an acceptable definition of that which in its nature is indefinable. However, the time may come when a provisional definition of motion may be established; until then a theory of structural motion cannot well be set forth. Looking over the old Carroll bridges it was found (by computation and gauging) that many members were stressed up to 25 000 lbs. per square inch without any visible evidence of elongation, loose rivets, etc. The observation of the speaker, confirmed by the study of structural motion, is that in railroad bridges free from undue motion a stress of from 20 000 to 25 000 lbs. per square inch need not always cause alarm, but much motion under low stresses may be of sufficient importance to suggest to the engineer an inquiry as to the validity of his grounds for the assumption of potential strength resident in his material.

An engineer handles forces primarily, and material secondarily. He is supposed to know the quantity of force stored up in his material, and also how long it can be kept there controlled and subject to the uses he intends, for "matter is force in bondage."

As to the magnitude of force immediately present in a piece of steel, for instance, its "properties" afford a criterion; as to the conservation of this force, its availability for repeated and long-continued service, and therefore the measure of the assurance and dependence thereon, "quality" offers a criterion. The speaker had not seen, so far, a specification for bridge material that indicated discrimination as to the difference between "property" and "quality."

GEORGE H. BLAKELEY, M. Am. Soc. C. E.—There are numerous Mr. Blakeley. recorded instances where riveted lattice railway bridges have withstood, without collapsing, the blows and shocks caused by collisions and derailed cars, while there are few records of pin-connected railway bridges standing up under such shocks. The number of riveted lattice railway bridges in use in this country is unquestionably less than the number of pin-connected bridges; consequently, it is reasonable to conclude that fewer accidents, in the aggregate, occur upon riveted lattice railway bridges than upon pin-connected. Notwithstanding this, the reported instances where the riveted type of bridge has successfully withstood severe accidents are far more numerous than for the pin-connected type. It does not necessarily follow that the pin-connected type is totally unfitted to withstand such accidents. The speaker is aware of several instances where pin-connected railway bridges have withstood tremendous shock and injury without collapsing, yet such instances were never reported or published in the technical press. The advocates of the riveted type of bridge are more earnest in their advocacy than those who have faith in the pin-connected type.

Charles W. Buchholz, M. Am. Soc. C. E., kindly furnished the speaker with a description of an accident to a double-track pin-connected bridge on the Erie Railroad. The character of the accident and the method employed by him in temporarily repairing the damage is of such interest as to warrant being given in detail.

Bridge No. 9, Delaware Division, was built in the fall of 1879. In February, 1890, a coal car on an east-bound train was derailed about 800 ft. west of the bridge, and running on the ties until it reached span No. 3 the forward trucks were slewed, and, mounting the guard ribbon at about the west end of span, the car crashed into the vertical post, L3, U3, as indicated in Fig. 5. The car broke this post off about 3 ft. above the center of the bottom chord pin, bending the upper portion of the post outward, and remained stationary with about one-third of the body of the car projecting outside of the truss, directly above the pin and partly supported by the lower end of the broken post, the forward trucks being shoved backward to near the center of the car. The car was a 50 000-lb. capacity hopper-bottom gondola loaded, the total weight being about 88 000 lbs.

The first thing done after the arrival of the wrecking crews was to hew out large triangular oak blocks to fit in the angle formed by the inclined end post and the top of the bottom chord bars close to the pedestal shoes. These blocks were placed on each end of the damaged truss, and on each of the adjoining spans. Twelve by fourteen-in. oak blocks were then placed close to the triangular blocks, and heavy wrecking chains with $1\frac{1}{2}$ -in. links were wrapped around the ends of each of the adjoining 12 x 14-in. oak blocks. Wedges were then placed between

Mr. Blakeley, the triangular and 12 x 14-in. blocks and driven home, thus bringing a good tension on the chains, and forming a connection to each span at each end of the damaged truss, so that it would be necessary either to break six ply 1½-in. chain, or drag one or both of the fixed spans off the pier or abutment, before the span that was damaged could be totally wrecked.

While some of the wrecking crews were connecting up the trusses, others were busy blocking and clamping the main bars L4, U3, L3, U2, and forming them into struts. Others were at work cutting cribbing pieces to distribute the weight over the lower chord, framing around the lower portion of the broken post, and making a bearing for a temporary post made of two pieces 8 x 18 ins. bolted together

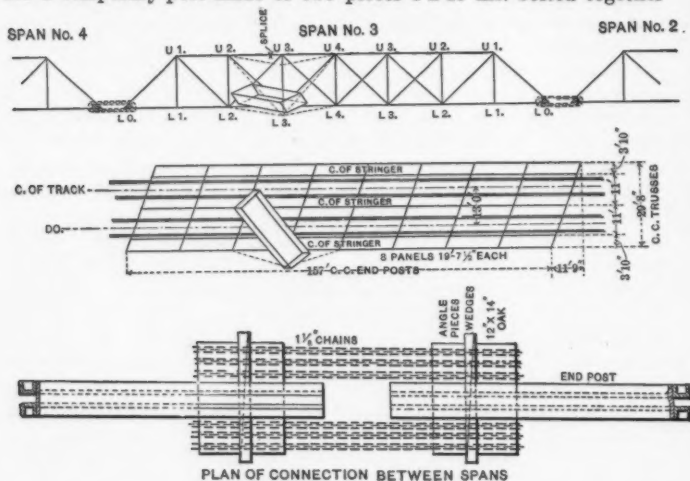


FIG. 5.

and fitting close to a crosshead timber on the under side of the top chord. While this was being done a gang of men was shoveling the coal out of the wrecked car. When the car was empty a wrecking car was run on the west-bound track by hand power, and the body of the coal car taken off, and afterward each of the two pair of trucks. When this had been done, the temporary post and cribbing that had been prepared were placed in position and wedged to a good bearing.

Traffic was then resumed on the west-bound track, and temporary bents, previously framed, were then placed in position under panel points L1, L2, L3 and L4 of the south truss for greater safety and in order to be prepared to change the temporary post when neces-

sary, and traffic was resumed on the east-bound track. Panel points Mr. Blakeley. L3, U3 were each about 3 ins. below camber during the time that wrecking was progressing, but were brought back to position, after temporary bents were placed and correct centers obtained, by adjusting the wedges between cribbing and temporary post, and the wedges between the temporary bents and bridges.

The top chord splice was located 18 ins. from the center of the pin, and while the rivets in side splices sheared off at this point, those in the cover-plate splice held.

This instance is not cited as an argument for the superiority of the pin-connected type of railway bridges, nor is it cited to disparage in any way the merits of the riveted type. The riveted type of bridge has many commendable features, and it is being more largely used for railroad bridges than heretofore.

JAMES OWEN, M. Am. Soc. C. E.—On one occasion a derailed coal Mr. Owen. car struck the cast-iron pocket under an end post of a pin-connected bridge on the Delaware, Lackawanna and Western Railroad. The bridge had an ordinary portal. The pocket was carried away, leaving the post without any support, but the bridge remained standing, although the first cross-girder sank $1\frac{1}{2}$ to 2 ft.

In designing highway bridges, the speaker long ago adopted a 100-ft. span as the limit of pin-connected work. Spans up to 85 or 40 ft. he now builds of rolled beams, and from that up to 70 or 80 ft. of plate girders. Most of his highway work is now made with beams and girders, with arches turned between them, and a concrete floor to carry the pavement. The dead load is largely increased in this manner, running up to about 300 lbs. per square foot, but the factor of safety can be reduced.

There are certain elements to be considered in highway bridge practice which need not be taken into account in designing railway structures. One of these is the vibration produced by fast traveling vehicles and light trotting wagons, which will cause more tremor in a bridge than will a heavy locomotive. In early pin-connected bridges, the speaker was continually troubled by lateral tie bars hitting the posts, and he was forced to bind the bars and posts together to prevent their rattling. This seemed essentially improper from an engineering point of view, and his later work has been built without any bars in it, all parts being stiff work of sufficient size to take up the vibration.

A rather curious loading for a plate girder bridge noticed by the speaker was caused by a contractor's poor judgment. A sewer had been built beside the structure, and the contractor had piled the earth on it until the load amounted to about 950 lbs. per square foot. The speaker looked underneath the span with considerable anxiety, but found no deflection.

Mr. Hardy. GEORGE R. HARDY, M. Am. Soc. C. E.—In the matter of vibration of tension members against posts, reference may be made to the fact that certain precautions had to be taken at the lower bridge at Albany, N. Y., to prevent the wearing of these members in this way. This bridge is a structure designed by the late Charles Hilton, and is pin-connected, a rather strange fact, in view of his later work being chiefly riveted. A few years later he designed the upper Albany bridge, which was a riveted structure entirely. Perhaps ten years later, the speaker asked Mr. Hilton's opinion as to the relative merits of the two systems of bridging, then a subject of considerable discussion, and he expressed himself very much in favor of the use of pin-and-link work under certain conditions. It would be interesting to learn of any good objection to such work in long deck spans where there is no opportunity for a catastrophe to be occasioned by the train service.

CORRESPONDENCE.

Mr. Thomson. T. KENNARD THOMSON, M. Am. Soc. C. E.—If all engineers had paid as much attention to painting as the author, there would be some bridges still standing which are now in the scrap heap. The writer has rebuilt bridges, which had stood rough and heavy traffic for twenty-five years, in which the iron was as good as new. In these cases they had been thoroughly cleaned and painted with pure red lead, and the iron had never been exposed. On the other hand he has condemned and rebuilt bridges which had been in use only a few years, but were dangerously pitted, although they had apparently been kept painted. The rusting had started and continued under the paint until scale $\frac{1}{8}$ in. thick could be picked off with the fingers from channels which were originally only $\frac{1}{4}$ in. thick.

Steel, after once rusting through the outer skin, seems to keep on rusting even if well painted, yet many bridge companies will not take steps to prevent this rusting starting, and some do not even see the use of removing the mud. Consequently there are many structures which have not been up a year in a worse condition than others after twenty to thirty years.

The writer once had charge for a railroad of replacing at the same time two old viaducts several miles apart. On arriving at one of these one day he found the foreman, supposed to be an exceptionally bright man, had knocked out the struts and eye-bars of some 30-ft. Fink trusses, leaving just one 15-in. I-beam 30 ft. long under each rail, and at least one-half the section had been cut from the center of these beams for the strut connection, etc. The ties had been left on 15 ft. of the 30-ft. span. The foreman argued that as these 15-in. beams

had carried the load unsupported for 15 ft., therefore it was just the same thing to have a 30-ft. beam span if it were loaded for only 15 ft. This was on a 6° curve, 2% grade, with heavy coal traffic; as it seemed impossible to convince him of his error, the trains were flagged and held until the viaduct was made safe. Had the writer happened to be at the other viaduct at the time, and he had more than enough to do at each place, the train and his reputation would have gone down. The viaduct was over 100 ft. high.

E. B. CUSHING, M. Am. Soc. C. E.—The author's belief that disastrous results would have followed had a pin-connected span been subjected to the same severe test as the lattice truss mentioned in the paper is no doubt correct. There are a number of cases on record where bridges of the former type have failed owing to the destruction of a post by being struck by a part of the load on an open car becoming displaced and projecting beyond the clearance line, or by derailed cars. While it is possible to reduce greatly the danger of accidents to pin-connected bridges by proper re-railing devices, the introduction of short struts to strengthen end-posts against shock, and other comparatively inexpensive means, it is hardly practicable to build a pin-connected span that would resist such a severe test as the one mentioned in the paper. The diffusion of strains over a number of points and the prevention of vibration are features that strongly recommend the rigid type of bridge. The ordinary bridge foreman, while perhaps duly diligent in keeping in repair the wooden trestles on his division, seems to regard the iron bridges as being able to take care of themselves, and unless constant watchfulness is exercised will permit these structures to get out of adjustment. The constant working of the members of a badly adjusted span under traffic sometimes causes injuries. This is especially true in the short pin-connected spans where the dead weight is so much less in proportion to the live load, and there is little to check vibration. The writer has never seen a bridge member fail under direct stress, but has seen instances where it became necessary to replace a web member, owing to injury through bad adjustment. In riveted spans this element is reduced to a minimum. Even the partial application of this type of construction, as, for instance, the riveting of stringers to floor beams, instead of the old method of placing them on the floor beams and the use of stiff braces instead of rods in trestle towers, has resulted in much more satisfactory practice.

Another point that recommends the use of girders and of lattice trusses for openings of reasonable length is the facility and rapidity with which they can be erected. Recently the Cleveland, Akron and Columbus Railway, in replacing a wooden Howe truss span, decided to use a 91-ft. plate girder. This girder was designed to carry two engines, each weighing 120 tons, followed by a train weighing 3 500

Mr. Cushing. lbs. per lineal foot. In order to cause no delay to traffic, while dispensing with the use of any falsework, the girders were riveted up complete on the cars. They were then swung on gallows frames and lowered into place. The entire time consumed, from the time cars were placed until trains were passed on the new tracks, was less than six hours. Such work would be impossible with a pin-connected span.

Riveted lattice spans require, generally, more metal than the pin-connected type, and the proportion increases with the length of span, so that the point at which it is necessary to adopt the latter type depends upon the extent to which owners of properties are willing to

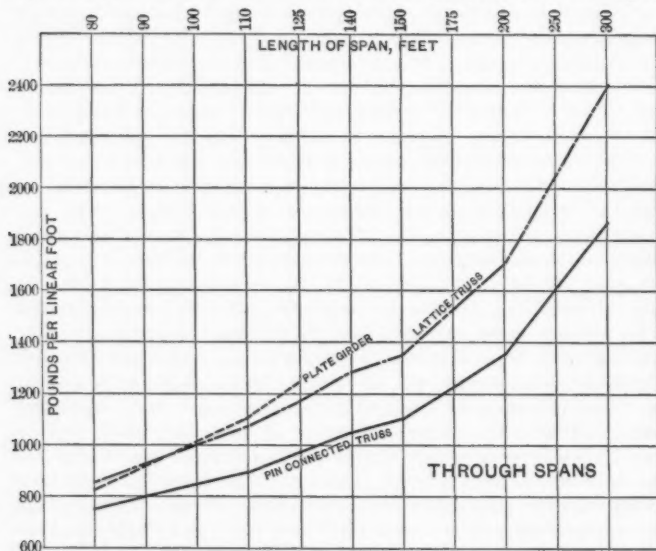


FIG. 6.

set aside first cost as the controlling feature in the consideration of alternate plans.

Using the general formulas for weights of bridges suggested by J. B. Johnson, M. Am. Soc. C. E., Fig. 6 has been calculated to show the weight per lineal foot of different types of bridges. Of course, these weights would vary with the different loadings assumed, and the formulas used are not claimed to be exact, but the results probably show the relative weight of the different types reasonably well.

From this it would appear that for a span of 200 ft. the pin-connected truss would weigh 20% less than the riveted truss, and for a

span of 250 ft. the difference in favor of the pin type would be 27%; Mr. Cushing. hence it is likely that the limit of 200 ft., suggested by Walter Katté, M. Am. Soc. C. E., at which the pin-connected construction shall begin, is not too conservative.

For the shorter spans there seems to be little doubt that rigid construction will become the general practice. In his last specification, Theodore Cooper, M. Am. Soc. C. E., extends the limits of rigid construction as follows:

Type.	Former Specification.	Latest Specification.
Rolled beam.....	16 ft. and under.	20 ft. and under.
Riveted plate girder.....	16 ft. to 70 ft.	20 ft. to 75 ft.
Riveted plate or lattice girder.....	70 ft. to 100 ft.	75 ft. to 120 ft.
Lattice or pin-connected truss	120 ft. to 150 ft.
Pin-connected truss	100 ft. and over.	Over 150 ft.

One of the former objections to the riveted type of bridges was the difficulty in transporting intact such long and heavy loads, and the consequent large amount of hand riveting in the field of the detached parts. This difficulty is now largely overcome by the greater capacity of cars and more intelligent methods of loading girders, so they may move laterally to conform with the chords of curves over which they are passing. In this way girders over 100 ft. long have been transported without any trouble, for considerable distances over railways having heavy curvature. Such movements are entirely safe if a reasonable limit of speed is maintained by the train in which the cars are moved.

Though some railways in their late specifications still adhere to their former practice in limiting to 75 or 80 ft. the spans for which girders are required, even expressing a preference for pin-connected types of spans exceeding the latter length, the writer believes that for spans of 100 ft. and under, plate girders will eventually become general practice, while pin-connected spans of less than 150 ft. will rarely be built on railways having heavy traffic.

The author properly remarks that engineers of the present day should be thankful to those who, in the face of opposition, laid the foundation for the present system of iron bridge construction. Now, when the results of years of careful research by the members of the profession has been crystallized into formulas, tables, charts and so on, the use of which reduces the minutiae of calculations so much, it is hard to realize the tedious labor necessary in early bridge designing. The profession owes much to those men who, like the author, first determined the course and then blazed out the way. It must be pleasant, indeed, for him to observe these monuments to his judgment and ability standing as mute but eloquent answers to those who opposed his efforts in the beginning.

Mr. Gray. GEORGE E. GRAY, Hon. M. Am. Soc. C. E.—The author is greatly interested by the discussion relating to early practice in bridge building. A few comments may not be out of place to complete history. The author's original designs, charts, strain sheets, and calculations for the iron bridges referred to, built on the New York Central Railroad prior to 1865, are still in his possession. Col. Carroll was his draftsman and assisted in making detail drawings, etc., and afterwards was entrusted with the supervision during construction of these bridges. He had but brief experience in iron bridge building before entering the service of the New York Central Railroad Company. Mr. Charles Hilton had in special charge the wooden bridges, buildings and other structures, but no experience in iron bridge building until the retirement of Col. Carroll, when that charge was added to Mr. Hilton's other duties. He could not be considered a pupil of Col. Carroll.

Mr. Hilton consulted the author in October, 1865, relative to the change of a plan previously prepared for a bridge contemplated over the Erie Canal, near Canastota. This change had been discussed at different periods, but the author objected to it, mainly because of the increased strain on the rivets, at the same time admitting the reduction of material. This latter was not considered an equivalent and the objection holds good to this day.